THE ANNALS

AND

MAGAZINE OF NATURAL HISTORY.

[THIRD SERIES.]

"................. per litora spargite muscum,
Naiades, et circùm vitreos considite fontes:
Pollice virgineo teneros hìc carpite flores:
Floribus et pictum, divæ, replete canistrum.
At vos, o Nymphæ Craterides, ite sub undas;
Ite, recurvato variata corallia trunco
Vellite muscosis e rupibus, et mihi conchas
Ferte, Deæ pelagi, et pingui conchylia succo."
N. Parthenii Giannettasii Ecl. 1.

No. 25. JANUARY 1860.

I.—*Observations on the Distribution and Habits of the Pelagic and Freshwater Free-floating Diatomaceæ.* By Surgeon G. C. Wallich, M.D., Retired List, H.M. Indian Forces.

THERE are three important points connected with the natural history of the Diatomaceæ upon which the information hitherto recorded appears both scanty and unsatisfactory. These are—

The laws whereby the bathymetrical range of these organisms, in their living state, is determined;

The conditions under which their silicious remains are deposited and form vast sedimentary strata;

And, lastly, the extent and nature of their locomotive powers.

In the 'Synopsis of British Diatomaceæ' (vol. i. Introd. p. xiii.) their distribution and habits are thus described:—

"Their living masses present themselves as coloured fringes attached to larger plants, or forming a covering to stones or rocks in cushion-like tufts, or spread over the surface as delicate velvet, or depositing themselves in a filmy stratum on the sand, or intermixed with the scum of living or decayed vegetation floating on the surface of the water. Their presence may be often detected, without the aid of the microscope, by the absence, in many species, of the fibrous tenacity which distinguishes other plants; and when removed from their natural position, they become distributed through the water, and are held in suspension by it, subsiding only after some little time has elapsed."

In the article on Diatomaceæ in the 'Micrographic Dictionary,' after a description of the methods for obtaining the fresh-water species "from the bottom, or from pieces of wood-work, &c., immersed in the water," it is stated that "many of them are entangled in the meshes of Confervæ and other Algæ, or on the submerged stems of higher plants,—*the deep-sea species*" being "obtained by dredging or by treating the alimentary canal of fishes, Mollusca, &c., with acid."

With two exceptions, immediately to be noticed, the above extracts embrace, as far as I am aware, a summary of the views entertained by writers on the subject; and they clearly indicate that none of the Diatomaceæ have, heretofore, been recognized as strictly free-floating organisms, but, on the contrary, that such forms as occur at times suspended in the water are considered as having been removed accidentally from their natural positions, and therefore evincing an invariable tendency to subside to the bottom.

Dr. J. D. Hooker was the first to notice the vast profusion of Diatomaceæ in the South Polar Ocean; and he pointed out their conspicuous appearance when imbedded in the substance of the ice or washed up on its surface by the action of the waves.

Still more recently, Assistant-Surgeon Macdonald, of H.M. Ship 'Herald,' in a brief but interesting paper on "Deep Soundings in the South Pacific" (published in the 'Annals of Nat. Hist.' for October 1857) offered the subjoined remarks on the subject:—

"Having ascertained with a certain degree of precision the nature of the material to be found in deep soundings off the coast of Australia and in the neighbourhood of the South Sea Islands, it is a discovery of peculiar interest to find the same minute organic forms, in vast numbers, mixed with the alimentary matter of Salpians and other pelagic animals observed in the open ocean, far distant from their shores.

"The presence of the silicious spicula and the fenestrated cells of *Thalassicolla* with the embryonic shells of the pelagic Mollusca might be readily accounted for. But how minute bivalves, Foraminifera, and a great variety of Diatomaceæ, and even Desmidieæ*, including the genus *Closterium*, and all apparently recent, could have been, as it were, casually inhaled, is not so

* In the plate accompanying Mr. Macdonald's paper, a *Closterium*-like body is represented, and referred by the author to the family named. A similar form has repeatedly been obtained by me from the same source. In external characters and colour it certainly exhibits the closest resemblance to a *Closterium*, but I was unable to detect either the terminal vesicles or the central suture.

easily explained. Such are the facts, however; and the means by which these bodies are so widely distributed are inscrutable, unless it be ultimately determined that they are in great part purely pelagic examples of the orders and genera to which they belong. This appears to be the most consistent view of the matter, seeing that the agency of drift-weed, or any other fortuitous cause, would be quite inadequate to produce so vast a result, even so far as mechanical dispersion is concerned, not to complicate the question with the more important part of the problem, namely, the preservation of the vitality and integrity of the beings under consideration."

I can most fully verify Mr. Macdonald's observations, having detected in the open sea, and widely distant from land or drift-weed, vast assemblages of minute animal and vegetable life, embracing every order to which he makes reference. My own observations, carried on during the voyage from Calcutta in the spring of the same year in which Mr. Macdonald's paper was published, led me to the following conclusions:—

That an inconceivable multitude of minute animal and vegetable organisms, the remains of which have been detected in deep-sea soundings, are, in their normal living state, strictly free-floating forms, inhabiting an extended bathymetrical range in the waters of the ocean. That the limits and variation of this bathymetrical range are determined by causes having reference partly to the condition of the atmosphere, and partly to the peculiar idiosyncrasy of the organism in question; the two sets of causes being influenced mutually, one by the other. That these floating pelagic forms constitute the principal source of food for the countless millions of minute animals which inhabit the open sea. And, lastly, that to the combined operation of such animals and those mightier zoophagists to whom the latter atoms afford, in their turn, a prolific prey, the submarine deposits of silicious and calcareous remains are, in a chief degree, attributable, the effects of natural death and decay being duly taken into consideration*.

* The late Professor Bailey of New York states (Journ. Microscop. Soc. vol. iii. p. 90) that Lieut. Berryman of the United States' Navy found "no trace of hard-shelled animalcules from specimens of water taken either at the surface or at any depths, at situations in close proximity to the places where the soundings were made, in the summer months, when animal life is most abundant;" and that "the animals present," some of which were, at the time of writing, "alive in bottles, were all of a soft, penetrable nature, leaving on their decay only a light flocculent matter, while the Foraminifera and Diatoms would have left their hard shells, if they had been present."

It is needless to say that these observations are quite inexplicable, unless on the assumption that the means necessary for the capture of all the smaller microscopic organisms were inadequate. At all events, a diametrically opposite result has been recorded by other observers.

Throughout the entire series of the two great kingdoms of nature, there is no class of objects so universally and lavishly distributed as the Diatomaceæ. In every latitude, on land and by sea, and under every known variation of temperature, wheresoever are combined the primary conditions of light and moisture, these minute but wondrously beautiful structures are to be found, in inexhaustible profusion.

Of their immediate purpose and uses we know little, as yet, beyond the bare fact that vast strata of the earth's crust consist more or less entirely of their silicious remains; that these strata have been formed, in bygone ages, as marine, fluviatile, or lacustrine deposits; and that, in our own day, similar strata are being gradually but incessantly built up, in the dark abysses of the sea-bed, far beyond the depths at which any living structures, with which we are acquainted, could meet with the conditions essential to their existence.

The strata referred to are, by some writers, described as "fossil" (or I should rather say that the Diatomaceæ discovered in those strata have been so considered),—an error at once obvious, from the fact of their silicious constituents existing now in precisely the same state as that in which they originally constituted the framework of the organisms by which they were eliminated and secreted.

This is a material point; and I am desirous of laying stress upon it, inasmuch as I conceive the deposits under notice not to be dependent wholly, or even chiefly, on the subsidence of these silicious frameworks, as the sequel to ordinary death and decay, but on the living structures being subjected, in numberless multitudes, to the processes of digestion; whereby, being divested of the bulk of the particles possessing any buoyant tendency, the mineral remains subside, by their own specific gravity, to the regions wherein they are finally entombed.

Some faint conception of their numbers may be gathered from what we see in the guanos, which present a considerable percentage of Diatomaceous exuviæ, and are thereby enhanced in commercial value. In most descriptions of the sources from whence the silicious element in guano is derived, it is stated that the birds producing this kind of deposit feed directly upon Diatomaceæ. Professor Carpenter suggests that the birds must have received these minute particles from the "shell-fish to which they serve as ordinary food."

Professor Quekett, in a paper on "The Examination of Guano by the Microscope" (Trans. Microscop. Soc. vol. ii. p. 29), thus writes:—"The silicious animalcules and sponge-spicules, it would seem, become present in the guano from, firstly, being devoured by fishes whilst adhering to sea-weeds or mingled with the sand; and, secondly, the fishes being devoured by the birds, they are voided with the excrementitious matter of the latter. As the guano localities are always above the level of the sea, and the species of animalcules yet discovered are all of the character that inhabit the bottom of the ocean, the most probable reason for their occurrence is that above described."

Now, with one or two rare exceptions, it would be easy to show that no Diatomaceous frustules exist of sufficiently large size to come within the focus of any bird's eye whatever. Nor could any vertebrate animal we are acquainted with, by any possibility, gather together, within a reasonable period, a sufficient supply of such infinitesimal nourishment as the Diatomaceæ afford, even granting that the optical difficulty were in any manner overcome. Again, no animal is known to possess prehensile or masticatory apparatus of sufficiently delicate arrangement to enable it to deal with particles so minute. The presence of Diatoms in guano, therefore, cannot be said to result from their constituting a direct source of food to the birds in question, but from their being the main source of food to the countless minute animals and animalcules, from the Crustacean and Mollusk down to the humblest hydrozoic being, on which the feathered tribes of the open sea depend for diet.

Touching the position assigned by Professor Quekett to the living representatives of all species whose remains have been found in the guanos, and assuming that the Diatomaceæ were included under the term "animalcules" (which was almost universally applied to these organisms at the time the paper referred to was written), it is only necessary to mention that in no instance have living Diatoms been brought up, by the sounding apparatus, from extreme depths. Frustules have been frequently obtained, containing the remains of the endochrome. But this proves nothing beyond the fact that the water, at those great depths, is so highly charged with saline particles as to render it capable of preserving, for an indefinite period, such portions of animal or vegetable matter as may sink to the bottom. It is highly probable, moreover, that, putting aside the Foraminifera, Polycystina, and Diatomaceæ, whose softer portions are included within a rigid mineral shell, nothing but the bleached skeletons of all the higher organisms ever reaches the bed of the ocean, every soft atom being resolved into its elements, either mechanically or chemically, long before it sinks to its final resting-place.

In the lowest forms of animal life, the absence of one set of functions is counterbalanced by the introduction of another. We thus find that a simple ciliary apparatus, working continually in the midst of an inexhaustible profusion of alimentary matter, answers all their requirements, and prepares them, in due course, to become food for creatures far removed from them as regards complexity of structure.

The pelagic Diatomaceæ have hitherto escaped detection chiefly because the means employed for the purpose have been inadequate. Indeed, their detection at all may be said to have been the result rather of accident than of any systematic endeavour to trace out the boundaries of their distribution.

The Diatomaceæ abound in all waters, more or less, but nowhere in such vast profusion as in the open ocean. Their presence there is in nowise accidental, or necessarily associated with that of foreign floating bodies, such as drift-weed, wood, &c. &c. It is well known that a large class of Diatoms consists of what are called "free forms," that is, of frustules possessing neither stipes nor mucous cushion or pedicle of any sort, whereby they might attach themselves to, or derive support from, other bodies; and that they are moreover endowed with a very peculiar and remarkable power of motion.

To these "free forms" belong the Diatomaceæ of the open sea; and there cannot be a doubt that the numbers in which they exist, in all latitudes, at all seasons, and at all depths (extending from an inch to the lowest limit at which the most attenuated ray of light can penetrate, or at which pressure permits), are immeasurably in excess of what we have hitherto been in the habit of assuming.

Nothing is more perplexing to the collector, at sea, than the apparently capricious manner in which the minute forms of organic life, both vegetable and animal, present themselves in and disperse from the surface waters. I have repeatedly observed the upper portion of the sea to burst forth suddenly, as it were, into a swarm of living particles, and these again as capriciously and suddenly to disappear. At one time, a slight change of temperature, or wind, or cloud, brings about such a result; at another, it follows upon influences unappreciable perhaps to our organs of sense, but at once indicated by barometric changes. During calms and bright sunshine, as might be anticipated, the assemblages of these vast masses of life are most frequent and constant, and especially so in the case of the Diatomaceæ; but this is by no means the invariable condition, as shall presently be shown.

My attention was, in the first instance, drawn to these remarkable objects by the phænomenon which presented itself in the Bay of Bengal and Indian Ocean, in March and April 1857. This consisted of an immense multitude of small yellow flocculi and tufts, with which the surface of the sea for some depth was crowded in sufficient quantity to impart to it a faint tint,—these tufts being intermixed with numerous glistening cylindrical bodies of a similar colour. A succession of calms, following one on the other, enabled me to trace this phænomenon, with but slight intermission, from 18° North lat. to 24° South.

On the Atlantic side of Africa the tufts alone were to be seen, and in smaller quantities, as might be expected from the stormy character of the sea. Without entering into a detailed description of these forms, I will merely state that the tufts were of two kinds,—one consisting of cylindrical filaments, closely resembling *Trichodesmium* in character; the other, of filaments of a *Rhizoselenia**. The flocculent masses, which when seen floating on the water resembled flakes of yellow cotton, were from half an inch to two, or even three inches in length, and proved to be aggregations of filaments of the same genus. The cylindrical bodies were gigantic *Coscinodisci*, each disk being distinguishable at a considerable distance from the eye, and even for several feet below the immediate surface.

I was at first induced to refer the whole of the tufts and flocculent masses to the Confervoid growths described as frequently occurring in the Red and Yellow Seas in such profusion as to tinge their waters of a reddish-yellow colour. The examination of the *Trichodesmium*-like tufts, which happened to come first under my notice, confirmed this view for a time; and it was not until a more extended analysis revealed the presence of the silicious forms, that the true character of the latter became apparent. *Salpæ* and *Diphyes*, taken previously in the upper portion of the Bay of Bengal, had already brought to light a considerable number of Diatomaceæ, specimens of which were now to be found entangled in the tufts and flocculi alluded to, imbedded in the substance of *Thalassicollæ*, or abundantly distributed in the alimentary matter procured from Salpians and other small creatures.

The mighty scale on which the Diatomaceæ really exist did not become manifest, however, until we reached the Atlantic, between the Cape and St. Helena.

It was here that, for many degrees, and in bright breezy weather, the ship passed through vast layers of sea-water so thronged with the bodies of a species of *Salpa* (*S. mucronata*) as to present the consistence of a jelly. These layers extended for several miles in length. What their vertical limits were, it was impossible to discover, owing to the speed at which the ship was moving. They appeared to extend deep, however, and in all

* This genus, as originally established by Ehrenberg, comprises forms widely distinct from the genus as now circumscribed by Mr. Brightwell of Norwich, and referred to above (Quart. Journ. Microscop. Soc., vol. vi. p. 93).

probability were of a similar character to the aggregations of what is called whale-food in the higher latitudes. Each of these *Salpæ* measured about half an inch in length; but so close was their aggregation, that, by a sudden plunge of an iron-rimmed towing-net, half the cubic contents, from which all water had percolated, generally consisted of nothing but one thick gelatinous pulp. Each individual presented a minute yellow digestive cavity, of the size of a millet-seed, which contained both Diatomaceæ, Foraminifera, and other organic particles.

If we take into account the numbers of Diatomaceæ and Foraminifera that must exist in order to afford even a small integral proportion of the diet of these creatures,—the vast renewal of supply that must be perpetually going on, and the equally vast multitude of these Diatom-consumers that yield, in their turn, a source of food to the gigantic Cetaceans and other large creatures of the sea,—it becomes possible, in some measure at least, to form an estimate of the manner in which the deep-sea deposits become accumulated.

Although no detailed investigations have up to this time been carried out with the special view of determining the bathymetrical ranges at which the Diatomaceæ, Foraminifera, and Polycystina of the soundings may be said to live, sundry vague and conflicting opinions have, here and there, been elicited during the recent inquiries into the nature of the sea-bottom, instituted under the auspices of the British, the Dutch, and the United States' Governments.

These opinions bear reference, however, almost wholly to the original habitats of such Foraminifera and Polycystina as have been traced in the soundings,—it being asserted by some that they lived and died at extreme depths, near the positions in which their shells were discovered; whilst by others it is contended that, having passed their lives in the various littoral regions of the ocean, their indestructible remains were gradually borne away by currents toward the situations at which they ultimately rested.

It is a notable fact, that both in guanos and deep-sea deposits the discoid forms of Diatomaceæ generally preponderate. In some deposits, as is well known, they constitute almost the entire silicious element, although frequently mixed with the calcareous exuviæ of Foraminifera, which, from their greatly superior size, form a large percentage of the mass. The abundance of *Coscinodiscus* in the Indian seas has already been adverted to; and, from observations made by me more recently amongst the Channel Islands, it appears highly probable that this form is the most largely distributed of the pelagic Diatomaceæ.

In contradistinction to the discoid forms, those of Naviculoid figure (using both these designations in their broadest sense) were comparatively scarce both as to species and individual numbers, and presented characters distinct from their non-pelagic congeners.

In the contents of the stomach of *Salpæ* and *Diphyes,* the discoid examples were numerous, although not of large size, as might be expected*. Among these may be named *Coscinodiscus, Eupodiscus, Asterolampra, Asteromphalus,* and *Triceratium.*

Rhizoselenia was always abundantly detected, but nowhere so profusely as in the mid-Atlantic, where the digestive cavities of monstrous *Salpæ,* measuring from six to seven inches in length, contained little else.

Temperature, within certain limits, has probably little to do with the bathymetrical distribution of the pelagic Diatoms; for it is well known that, whereas in the equatorial regions the temperature decreases with the depth, at a tolerably fixed rate, until it becomes stationary (or only subject to slight variation) several degrees above freezing-point,—in the Polar region the converse process takes place, the temperature increasing from above with the depth, and approaching to the standard which is probably universal near the bed of the ocean.

The question to what extent the subsidence and deposit of minute organic remains may be influenced by oceanic currents, can hardly be considered as bearing on the present subject. It will be a point for future investigators to decide, how far the results observable in such a case can be rendered expressive of their causes. Or, should this, in its literal sense, appear a visionary hope, we may, at all events, expect, by examining facts as presented, to augment our practical knowledge of the sea, and, with it, our means of verifying other and more palpable phænomena.

Again, it seems highly probable, from what has been adduced, that these vast aggregations of minute vegetable life, and (what is of equal value as affording collateral evidence of their presence *somewhere* in the neighbouring depths) of the minute creatures which subsist upon them, exist in different vertical zones, which are partly determined by atmospheric conditions, and partly by peculiar idiosyncrasies of the organism upon which those atmospheric conditions operate.

In the present state of our knowledge of their life-history, anything beyond a notice of the most easily recognized and demonstrable of these conditions would be futile. Nevertheless I shall endeavour to show that, as regards the Diatomaceæ,

* The *Coscinodiscus* referred to as being so conspicuous in the Indian waters is probably the largest Diatom known, the valve at times measuring one-twentieth of an inch in diameter.

certain well-known laws, which influence the vegetable kingdom generally, exercise an additional and very powerful influence in their diffusion from one bathymetrical zone to another; and that, too, apart from the peculiar inherent power of locomotion exhibited by this remarkable class of organisms.

Light and moisture constitute the indispensable requirements of the Diatom. Without these, its vitality at once ceases. But these requirements are essential only in a very modified degree. In other words, an amount of either so limited as to annihilate every trace of life in the higher types, is not only capable of sustaining that of these lowlier ones, but of sufficing for every purpose of luxuriant growth and reproduction.

It is impossible not to be struck with the exuberant and rich development of endochrome seen in all the floating frustules. Nothing can exceed the vividness of colour or massiveness of the endochrome-granules in the several species observed. The frustules procured direct from the water were invariably full of these particles, whilst such as were obtained, at second hand, from the digestive canals of the minute phytophagists within whose bodies they were found, exhibited the frustules in every condition intermediate between that just described and emptiness—the exponent of accomplished digestion. In the latter case we have the state in which the silicious skeleton is extruded and now permitted slowly but surely to accomplish its journey to the bottom.

How far these minute frustules may have travelled from that point at which, succumbing to the limits imposed on their individual existence, or captured as food, they first began their descent as mere motionless atoms, it would be vain to surmise. One thing is certain—that, to whatever extent their ultimate destination may have been influenced by the mightier and more determinate currents of the ocean, they must also have been swayed to and fro, for indefinitely protracted periods, by those numberless fainter heavings which, although unmarked by the plummet, are nevertheless all-powerful in relation to such particles.

The spores of the freshwater Algæ afford evidence of the wonderful amount of vital resilience, so to speak, with which these structures are endowed,—being capable of withstanding long-protracted periods of desiccation under tropical heats, or congelation under Arctic cold, without losing those reproductive energies in the absence of which their tribe would be annihilated. This power belongs in a very marked manner to the sporangia of the Desmidiaceæ and Diatomaceæ, as is well known. In all probability, therefore, the pelagic Diatomaceæ possess some equivalent property, in virtue of which they can the more readily accommodate themselves to the varying, but mighty, agencies of the ocean.

The tendency of the Diatom to approach the source of light and heat is fully understood. It shares that tendency with all other vegetable structures, although, from the fixed nature of the higher orders, the effects are perhaps not so palpably recognized. But there exists, it appears to me, quite sufficient evidence to prove that this quality is entirely distinct from, and independent of, the peculiar motile power upon which its animal character was so long and so erroneously maintained. The one phænomenon is simply the result of those physical conditions by which the growth and increase of the organism are determined; the other depends upon peculiarities of structure or function which, although imperfectly understood, must nevertheless be considered as imparted to it for the purpose of bringing it into contact with fresh portions of the medium it inhabits, or of enabling it to accommodate itself to the requirements of the conjugative process.

Last year, among the Channel Islands, it was my good fortune to meet with a repetition of the phænomenon witnessed by me in the Indian seas. As in the former instance, my attention was first attracted by the occurrence, during calm spring weather, of large frustules of a *Coscinodiscus,* viz. *C. concinnus*. The surface and depths, as far as the eye could pierce from the gunwale of a boat, were thronged with the brilliant, glistening cylinders of this Diatom, intermixed with filaments of *Biddulphia Baileyii*, and, more sparingly, with the long acicular threads of *Rhizoselenia* and *Chætoceros*. The self-buoyant property of these coast-frequenting forms, although of a temporary character only, is nevertheless evident, and indicates that they hold a position intermediate between the perpetually free-floating species of the open sea and the subparasitic species of the fresh water, which, although capable of self-support for brief periods, are generally to be found in the neighbourhood of aquatic plants or other objects.

As it happens, *Coscinodiscus concinnus, Biddulphia Baileyii*, and the several species of *Rhizoselenia* are amongst those forms sometimes designated as "imperfectly silicious." Their distinctness as species can, however, in nowise be influenced by this character. The quality of the silicious framework is, after all, resolvable into a question, not of imperfect (that is, impure) silicious secretion, but of the relative thickness and solidity of that secretion in these as compared with other forms. If it be for a moment contended that the silicious structure is *permeated* by any structure of vegetable origin, whether protoplasm or endochrome, or cellulose, the only consistent view of the silicious portion of the frustule must at once be set aside. Professor Bailey's observations with reference to the behaviour of the Diatom when treated by hydrofluoric acid are conclusive on this point. The *external* silicious framework is consumed. The internal cellulose cell-membrane remains intact, leaving no trace of any delicate network, such as we should certainly find were it associated with the substance of the silicious portions. On the other hand, the substance of the silicious valves (after being subjected to hydrochloric and nitric acids) *in no case* exhibits evidence of permeation by other matter.

The frustules of certain species, it is true, are more readily broken up under the action of acid; but under no circumstances can nitro-muriatic acid *destroy* a film of silica, however delicate.

Forms accidentally removed from their natural habitats, and thereby placed under conditions for which they are unfitted, naturally enough, present examples of imperfect deposition of silex, as to *quantity,* but not as to *purity.* Such a state occurs in freshwater forms exposed to brackish water, or *vice versâ.* But these are exceptional cases, and cannot be allowed to weigh in our estimate of normally developed forms. As regards the Diatoms more particularly noticed as falling under the modified silicious examples, it is only necessary to state that specimens subjected to boiling, for many hours, in the most concentrated acids, in no single instance presented appearances which could be interpreted into an obliteration of the silicious envelope.

The true significance, I would suggest, of the delicate nature of the silicious element in the Diatomaceæ under review consists in a simple adaptation of the means to the end—in the lightening of the mineral framework as far as is compatible with the requisite strength, and its being made to enclose the greatest possible space, in order to admit of that luxuriant development of the endochrome and protoplasmic contents, in virtue of which the specific gravity of the frustule is diminished and its buoyancy secured.

Light and pressure seem to be the main causes that impose limits to the wanderings of these organisms. It has been shown that their buoyancy must vary with the intensity of the conditions necessary to their development; and we are justified in concluding, moreover, that there are periods in the history of the structure at which their development and reproductive phænomena proceed most vigorously. Their bathymetrical position must therefore also be a fluctuating one; and we can thus satisfactorily account for the seemingly capricious manner in which they approach, or disappear from, the surface of their element.

We have therefore before us an answer to the problem, why these organisms appear near the surface more readily in calm and bright weather. It is only during such conditions of the atmosphere that the refractive power of the medium they inhabit remains undisturbed by the surface-tumult; the rays of light and heat penetrate freely into the depths, and produce, by their combined influence, the amount of development under which the ascent to the surface takes place*.

It will be obvious that buoyancy and development of endochrome must proceed *pari passu,* when we recollect that the silicious skeleton, once formed and consolidated, ceases to grow, and therefore that the increase of the lighter contents must materially diminish the specific gravity of the entire frustule.

Of course the development of the freshwater forms depends on precisely the same laws as that of the pelagic ones; but their buoyancy is constantly obscured by entanglement amongst Algæ and other bodies mixed with the water in which they reside. There are two easily available modes in which the buoyancy of certain freshwater species, and the powerful light-seeking tendency of others, may be tested. The first consists in carefully scooping up, during bright sunny weather, a portion of the water in the immediate neighbourhood of the larger Algæ; the second, in watching how rapidly the mud-inhabiting species cover a muddy bank (which, during stormy weather, exhibited not a single frustule) with a uniform layer of glistening and satin-like yellow.

Lastly, the spaces frequently traversed by the Diatomaceæ are such as to be quite irreconcileable with the ordinary alternating to-and-fro motions they exhibit; for, even granting that this kind of motion were capable of being continuously exercised in any given direction, the speed achieved by it would be quite disproportionate to the distances travelled over.

Having thus far endeavoured to trace the influences which determine the general limits of the Diatom as to depth, and its transition from one bathymetrical range to another, it remains for me to state the result of an extended series of observations, conducted with a view to ascertain the precise agency whereby the ordinary motile power of the free species is produced.

Did space permit, or were it necessary after what has fallen from the pen of the late Professor Smith on the point, I might

* It is well worthy of note that the ordinary to-and-fro movements of the Diatomaceæ appear to be carried on quite as energetically under artificial as under solar light. But artificial light does not bring them to the surface as solar light does,—clearly proving that the ascent of the free-floating forms from the depths is *not* due to the ordinary motile power of their frustules.

discuss the statement of Professor Ehrenberg as to his having seen "moveable retractile cirrhi," on a species of *Surirella*, bearing a resemblance to "the feet of the sea-stars," by which locomotion was effected.

As it is, I would observe that, having repeatedly seen the peculiar appendages described by Professor Ehrenberg and recognized by Professor Smith, I have shared the inability of the last-named high authority to distinguish the slightest evidence of motile power. Prof. Smith states that he never saw the appendages *move*. In so far as relates to their being deflected, one after the other, during the transit of the frustule to which they were attached past impeding objects, I have certainly seen *movements*; but these movements were precisely of a character to furnish the most conclusive proofs *against* their being *organs of locomotion*, or indeed anything more than epiphytic appendages which, like the teeth of a comb, when drawn across an object, become the exponents and not the source of the force employed.

Before proceeding further, I must avow that, whilst I am prepared to indicate the *kind* of organs possessed by the Diatomaceæ, I have hitherto failed in rendering them visible under the microscope, even with all the delicate appliances of an instrument of the most perfect construction.

In venturing to prove my position, I rely on two facts: viz. that the hypothesis offered is sufficient to account for the entire series of phænomena, and that the phænomena observed are wholly irreconcileable with any other hypothesis.

Under this difficulty, I may perhaps be permitted to record, in the first place, the several conditions under which the living Diatom may be seen to move and to *exert an influence upon* minute particles in its course; and then to point out the nature of the organs by which alone I conceive those conditions can be effected*.

The normal motion of the Diatomaceous frustule is in two opposite directions, which accord with its longest diameter. It is of a smooth, gliding nature, devoid of jerks or interruptions, and exhibits itself at tolerably regular intervals. The rate at which it travels is not uniform, being subject to variation on increase or diminution of light and warmth. The rate is also materially influenced by the condition of the endochrome, the motions being invariably more active and energetic when the frustule is full. On the other hand, as soon as the contents shrink, and more especially on the appearance of vibratile

* The appearances about to be described may be readily seen in any of the commoner Naviculoid species. If kept in saucers for a day or two, they will rise to the surface, in a sufficiently pure state to admit of accurate observation.

granules, the movements become either wholly or partially arrested.

The power of turning on the long axis also exists, and, further, of wheeling round on the centre abruptly. It is probable, however, that this last kind of motion is effected only when the frustule happens to be obstructed in its course by foreign particles, or between the glass slide and cover of the observer. When thus impeded, the smooth gliding character of the motion becomes destroyed, and in its place may be seen a somewhat "drunken" or, at times, jerky progress. This, although evidently due to the abnormal position in which the Diatom happens to be placed, proves of the highest value, as will be presently understood, in arriving at a proper view of the question before us.

When a frustule comes into contact with particles of matter in its vicinity (as constantly occurs whilst it is under the eye of the observer), it either cleaves its way steadily and slowly through them, or, by a series of abrupt jerks, becomes freed from the obstacles, and continues its progress, with perhaps some slight change of its original direction. Should the particles prove too heavy for its powers, or too firmly fixed, the jerks nevertheless are continued, until, on the recurrence of the retrograde interval, the frustule reverses its direction and retires from the obstructing particles.

But, instead of merely thrusting aside a particle in its way, the Diatom may frequently be noticed to seize upon it, and carry it along with it for an indefinite period on one or other of its surfaces—often, moreover, in an opposite direction to that pursued by the frustule for the time being. It is not by any means essential that the particle laid hold of should be placed directly in its path, or even very close to it; for, at times, without any connecting bond of union being detected, the particle is forcibly drawn towards the moving frustule, and is either released after a while, or subjected to the handling above referred to.

The Diatom may, again, pass over, or under, or through a mass of impeding objects, and may appear for a time as if it had got clear of these. Such is not the case, however. When it has advanced *to some distance*, the particles are suddenly observed to be bound together, as it were, and to follow accurately in the wake of the frustule, the relative positions and distance being accurately maintained. Should the frustule, with its particle or particles "*in tow*," now meet with any sudden impediment, the instant it is checked in its course, so is the particle,—every jerk, turn, and movement of the body dragging being synchronously and faithfully repeated by the particle dragged.

Having been "towed" along as just described, the particle may all at once be suddenly drawn towards or upon the Diatom, when similar phænomena to those above noted are perhaps again repeated.

At times the course of events is changed. The Diatom cleaves its way, and evades or pushes through an obstacle which is sufficient to check the particle it happens to be dragging behind it. We now see the Diatom suddenly arrested, at the *precise* instant that the obstacle is observed to take effect upon the particle. Again the Diatom jerks, as if endeavouring to free the obstructed particle by dragging it through the obstacle, and again every jerk and movement are most faithfully repeated by the particle in tow and also by the obstacle it is impeded by. Should the force exercised prove insufficient to release the particle, one of two events occurs:—either the bond of union, whatever it may be, appears suddenly to break or relax, and the Diatom springs forward on its course; or, at the end of the usual alternating interval, the bond of union being still retained, the frustule retraces its steps.

In this last event, a very remarkable phænomenon may be witnessed. The Diatom either manages to pierce or to evade the obstacle which impeded the particle it had "in tow," and frees it by causing it to recede from instead of advancing through the obstacle; or, having released its hold, it advances alone, leaving the particle motionless. Sometimes the Diatom appears to "anchor" itself to a spot, and the particle, should one be retained "in tow," instantly stops. But, although at a considerable distance, it may be observed to experience jerks and movements utterly incompatible with any forces except such as *must* originate with the Diatomaceous frustule. Or, although the frustule is evidently anchored in some way, and thus enabled, generally speaking, to withstand the recoil shock or jerk due to the force it has applied, the unmistakeable connexion between some jerk of the particle it is applied to and the corresponding recoil the frustule exhibits leaves no possible room to deny the sequence of the two events as cause and effect. And, lastly, the whole of the above phænomena may occur between a frustule and one or many such particles of matter.

These, then, constitute some of the most striking appearances which bear directly on the problem before us. In avoiding the complications that must have arisen had I attempted to depict all the modifications they are liable to under a variety of accidental circumstances of no significance one way or the other as relates to the point to be proved, I should have become simply unintelligible.

The view entertained by Professor Smith, and indeed by the generality of authorities, respecting the movements of the Diatomaceæ, may be best stated in the paragraphs from the 'Synopsis' (vol. i. p. xxiii):—

"Of the cause of these movements I fear I can give but a very imperfect account. It appears to me that they do not arise from any external organs of motion. The more accurate instruments now in the hands of the observer have enabled him confidently to affirm that all statements resting upon the revelations of more imperfect object-glasses, which have assigned motile cilia or feet to the Diatomaceous frustule, have been founded upon illusion and mistake. Amongst the hundreds of species which I have examined in every stage of growth and phase of movement, aided by glasses which have never been surpassed for clearness and definition, I have never been able to detect any semblance of a motile organ.

"I am constrained to believe that the movements of the Diatomaceæ are owing to forces operating within the frustule, and are probably connected with the endosmotic and exosmotic action of the cell. The fluids which are concerned in these actions must enter and be emitted through the minute foramina at the extremities of the silicious valves; and it may be easy to conceive that an exceedingly small quantity of water expelled through these minute apertures would be sufficient to produce movement in bodies of so little specific gravity."

Had it only been necessary to explain the ordinary and separate movements of the Diatomaceous frustule, the theory of endosmotic and exosmotic action might perhaps have been deemed satisfactory. But the moment we come to consider the behaviour of the frustule with reference to minute objects in its vicinity, and duly interpret the phænomena I have endeavoured to describe, and which are inseparable as cause and effect, it becomes evident that no such action can, by any possibility, account for them. To explain such phænomena consistently, we are irresistibly, as I conceive, led to one inference, namely, the existence of elongated prehensile filaments, capable of alternate extension and retraction, of extreme tenuity, yet of extraordinary strength and elasticity,—in virtue of which both the ordinary to-and-fro motions and the secondary motions affecting surrounding bodies are performed.

All "free" Diatomaceæ may be held to possess these organs. But where they emerge, whether they arise in one, or two, or several pairs from each valvular extremity, and whether they are to be considered as processes sent out from the primordial utricle, it would be foolish, at present, to hazard an opinion.

If it has not been deemed rash to assume the existence of endosmotic and exosmotic action in solving the problem before us, surely it cannot be so to assume that of prehensile organs of the kind shadowed forth. In the one case the alternating action in opposite directions has no parallel. On the contrary, looking at the unicellular nature of the Diatomaceous frustule, we are at once met with strong negative testimony. Not so, however, with regard to the motile filaments; for we are presented with analogous phænomena in the spores of certain Acrogenous plants, which move from place to place by the alternate expansion and contraction of the hairs with which they are furnished.

Or, if we are inclined to admit an analogy between the prehensile and motile organs now spoken of and the pseudopodia of the Rhizopods—or, to go yet a step further, if we look at the contractile pedicels of certain Infusoria, we are provided with examples from the animal kingdom of the occurrence of similar, or very nearly similar organs.

From the character of the primary movements of the Diatom, and those secondary movements which are produced by its instrumentality on objects in its neighbourhood, it is highly probable that the prehensile and active portion of the organs is chiefly confined to their extremities,—their stem being somewhat rigid, and thereby unfitted to create currents amongst minute foreign particles at its point of exit. Of filaments of this nature we have examples, although on an enlarged scale, in certain Monadina (*Monas attenuata*, for instance), and certain Euglenæ, such as *Peranema globulosa*. By such organs we might naturally expect to see particles in the vicinity of a Diatom grasped and swayed about, precisely as occurs in reality, at the same time that the ordinary motions are produced.

Professor Smith has stated that, on colouring the water with "carmine or indigo, he had never been able to detect in the coloured particles surrounding the Diatom those rotatory currents which indicate, in the true Infusorial animalcules, the presence of cilia." But, surely, had endosmotic and exosmotic action been the real source of motion, similar currents *ought* to have attended the *expulsion* from the apertures of even so small a quantity of water forcibly enough to create those movements.

The same writer has also stated (Synops. vol. i. p. 23) that "motion may at times be detected in other forms than the free species; as those of *Gomphonema*, when forcibly separated from their stipes, occasionally exhibit an evident tendency to change their position;" but that such motions are devoid of the *isochronous* quality so notable in the others.

This is precisely what might be looked for, as I conceive the stipes and cushion-like masses of the pedunculate and filamentous forms to be merely modifications of the filament in one or both directions; and it is highly probable, therefore, that the remarkable unsymmetrically arranged processes referred to by me (Quart. Journ. Micr. Science, vol. vi. p. 423) as occurring in both species of the genus *Hydrosera,* and also to be found in several Indian stipitate forms, are in reality apertures, through which the modified filament is extended. Of course, in the discoid forms, the marginal processes would perform the same office*.

In *Bacillaria paradoxa* we have to assume the presence of a *highly* elastic envelope, embracing the entire filament, to enable us to conceive how the several series of prehensile filaments may produce the curious movement which that form exhibits. That such envelopes are to be found both amongst the Diatomaceæ and Desmidiaceæ, is well known. And in proof of the elastic character which analogous structures may possess, it is only necessary for me to state that, from observations made by me on an Indian species of *Schizonema,* the character spoken of was remarkably seen in the enveloping gelatinous sheath,—each frustule, after passing along in continuous and regular order till it reached the torn orifice of the sheath, being there suddenly and very forcibly expelled to some distance.

I may, in conclusion, add that every effort to render visible the filaments whose existence I assume, either by iodine or reagents, has hitherto failed. In the endosmotic and exosmotic theory of Professor Smith, it became necessary to assume not only as much, but more,—the evidence of currents, which were *essential* to its truth, being deficient. But it is surely unphilosophical to deny the existence of all we are unable to *see.* We may still hit upon some vegetable colouring or dyeing matter, of *innocuous quality to the Diatom,* but capable of staining its most delicate portions. This innocuous character is essential, inasmuch as in any attempt to detect the nature of highly delicate organs, such as the most attenuated ciliary apparatus or

* A novel form of *Coscinodiscus* (provisionally named by me *C. Sol*) is found in the stomach-contents of *Salpæ.* It has a broad membranous plate extending round the periphery of the silicious disk, across which are arranged, radially, very delicate folds *springing from the margin of the silicious portion.* This membranous plate may be looked upon as another modification of the filamentous organs. The occurrence of so very remarkable an appendage to a Diatom affords a valuable confirmation of the view given above.

It may be mentioned that, on exposure to acid, the membranous plate is dissolved, but the silicious disk remains and is then *undistinguishable* from an ordinary *C. radiatus* of small size. Specimens in my possession exhibit the two valves and plates in all their integrity.

motile filaments, our first *glimpse* is generally a passing one, caught during the instantaneous production of a shadow. Or, although our objectives may already be considered almost perfect, that perfection is capable of increase, and we may therefore hope, by a single step in advance, to render the *unseen* of today *the thing seen* of tomorrow.

II.—*Revision of the Family* Pennatulidæ, *with Descriptions of some new Species in the British Museum.* By Dr. John Edward Gray, F.R.S., V.P.Z.S., P.E.S. &c.

[With two Plates.]

Dr. Herklots, the curator of the Royal Museum at Leyden, has lately published in the last Part of the 'Bijdragen tot de Dierkunde,' part vii. 1858, a monograph of this family, describing and figuring several new species. I shall use his work as the basis of this communication, as far as regards the species he describes, which I shall attempt to divide into groups for more easy determination.

Tribe I. Funiculineæ, or *Junciformes,* are elongated Sea-pens with very small pinnules.

A. *The Cells armed with spinules.*

1. Funiculina, Lamk.

* *Axis quadrangular.*

1. *F. quadrangularis,* Johnston, Brit. Zooph. t. 31. Scotland.

** *Axis cylindrical.*

2. *F. Christii,* Sars, Fn. Litt. Norv. ii. t. 12. f. 7–12. Coast of Norway.

3. *F. Finmarchica,* Sars, Fn. Litt. Norv. ii. t. 11. Coast of Finmark.

B. *Cells fleshy, not spinulose.*

2. Virgularia, Lamk. Axis stony, tapering at each end. Cells not produced.

* *Pinnules well developed, digitate, diverging from the rachis.*

1. *V. Vanbenedensis,* Herklots, Not. 11. t. 7. f. 7. *Hab.* ——.

2. *V. Ellisii.* Elongate. Rachis cylindrical. Base elongate, nearly one-third the entire length; lower part much dilated, club-shaped. The lower pinnules adpressed, far apart, nearly transverse as regards the rachis; the upper ones lunate, far